

FINAL REPORT

NASA CONTRACT NAG-1-1447

7N-93

412058

THEORETICAL EVALUATION OF THE RADIATION HAZARDS FROM COSMIC RAYS
WITHIN SPACE VEHICLES

UNIVERSITY OF NEBRASKA-LINCOLN 68588-0111

DEPARTMENT OF PHYSICS AND ASTRONOMY

ROBERT KATZ, PRINCIPAL INVESTIGATOR

I. This investigation has proceeded as specified in the proposal dated 1 January 1992. Results have been presented orally at many professional meetings, have been published in refereed journals, and as NASA technical papers. In large measure our progress has resulted from collaboration with NASA personnel, principally F. A. Cucinotta, J. W. Wilson, and others.

2. We may summarize our efforts as follows:

a. Improvement of our calculations of the radial dose distribution from delta rays ejected in the passage of heavy ions through matter through the application of new data to a previous calculation by Kobetich and Katz (1968). Supplementing this calculation, we have found the radial distribution of electron energy spectra and the radial distribution of microdosimetric quantities (Cucinotta et al, 1996, 1997)

b. Extension of the Katz model of cellular survival to bacteria, to lethal mutations in *C. Elegans* in vivo, to mutation induction in vitro, to thindown in radiobiology (observed experimentally at GSI, Darmstadt, and there called "Darmstadt hooks", predicted by Katz theory years before GSI was constructed).

c. Coupling the Katz theory of RBE to the NASA theory of the diffusion of heavy ion beams in matter (including target and projectile fragmentation) to yield predictions of radiobiological effects for monoenergetic heavy ion beams as well as range modulated beams used for cancer therapy. Here we have directed attention to the role of "ion-kill" (the effects produced by heavy ions passing through the nucleus of a cell), responsible for increased RBE, decreased OER, and reduced repair. We predict that the use of beams of heavy ions in cancer therapy will create late effect problems for fractionated therapy. We highlight also the damage by "ion-kill", from single heavy ions in the cosmic rays, to the central nervous system in space flight.

d. The coupling of Katz theory and the NASA theory of heavy ion diffusion and penetration through matter, and knowledge of the space radiation environment, has been applied to design of shielding, to the cell damage in space flight.

e. As yet we have not contributed to the design of dosimetric systems yielding knowledge of the ion kill and gamma kill damage fractions in space flight. We have suggested that this might be accomplished through use of one and two hit detectors, such as TLD's.

f. As yet we have not calculated the response of cells in vitro to neutrons currently used in cancer therapy, though is contemplated. We wish to examine the implications of ion-kill from heavy fragments in neutron therapy and thus to estimate problems with neutrons in space flight.

g. Our studies of ground based experiments in radiobiology and in cancer therapy are made to substantiate our theoretical model of the biological effects of energetic heavy ions, which, incidentally, is the only predictive model in this discipline. In support of this claim we point out that we have predicted the effects of single protons and single alpha particles incident on cell nuclei, in the latest microbeam experiments. These predictions are made from Katz theory, and the cellular radiosensitivity parameters extracted from experiments at high LET and high dose levels. The theory then predicts response at the lowest possible fluence levels (single electrons and single heavy ions).

All funds available in the present contract have been expended.

PUBLICATIONS, PRESENTATIONS, REPORTS

7/1/92 - 10/31/98

I. Publications

R. Katz and F.A. Cucinotta, RBE VS. DOSE FOR LOW DOSES OF HIGH LET RADIATIONS, Health Physics 5, 717-718 (1991).

F.A. Cucinotta, R. Katz, J.W. Wilson, L.H. Townsend, J. Shinn, and F. Hajnal, BIOLOGICAL EFFECTIVENESS OF HIGH ENERGY PROTONS: TARGET FRAGMENTATION. Radiation Research 127, 130-137 (1991).

F.A. Cucinotta, J.W. Wilson, L.W. Townsend, J.L. Shinn and R. Katz, TRACK STRUCTURE MODEL FOR DAMAGE TO MAMMALIAN CELL CULTURES DURING SOLAR PROTON EVENTS, Nucl Tracks and Radiat. Meas. 20 (177-184) (1992).

R. Katz, RELATIVE EFFECTIVENESS OF MIXED RADIATION FIELDS, Radiat. Res. 133, 390 (1993).

R. Katz and R. Zachariah, EXPERIMENTAL AND THEORETICAL CROSS SECTIONS FOR E. COLI MUTANTS B, B/r and B_{s-1} AFTER HEAVY ION IRRADIATION, Radiat. Res. 134, 261-264 (1993).

R. Katz, F. A. Cucinotta, J. W. Wilson, J. L. Shinn and Duc M. Ngo, A MODEL OF CELL DAMAGE IN SPACE FLIGHT. in Biological Effects and Physics of Solar and Galactic Cosmic Radiation, Part A. Eds. C. E. Swenberg, G. Horneck and E. G. Stassinopoulos. Plenum Press, New York 1993, pps.235-268

F.A. Cucinotta, J.W. Wilson and R. Katz, RADIOSENSITIVITY PARAMETERS FOR LETHAL MUTATIONS IN C. ELEGANS, Radiation Protection Dosimetry 52, (1994).

R. Katz and M.P.R. Waligorski, ON THE LINEAR EXTRAPOLATION TO LOW DOSES, Radiation Protection Dosimetry 52, (1994).

R. Katz, DOSE, Radiat. Res. 137, 410-413 (1994).

R. Katz, REPLY TO D. E. WATT, A. S. ALKAHARAM, M. B. CHILD AND M. S. SALIKIN; DOSE AS A DAMAGE SPECIFIER FOR RADIATION PROTECTION, a comment on DOSE by R. Katz. Radiat. Res. 139, 251-253 (1994)

R. Katz, R. Zachariah, F. A. Cucinotta and C. X. Zhang. A SURVEY OF CELLULAR RADIOSENSITIVITY PARAMETERS, Radiat. Res. 140,356-365 (1994)

R. Katz, R. Zachariah, C. X. Zhang, and F. A. Cucinotta, TRACK THEORY IN RADIATION PROTECTION AND THERAPY, "Heavy Ions Research" Sofia Antipolis, France, March 1994. (unpublished)

R. Katz, M. N. Varma and C. X. Zhang, RADIAL DOSE DISTRIBUTION: THE FOUNDATION OF TRACK THEORY. India, 1994 (unpublished)

F. A. Cucinotta, R. Katz, J. W. Wilson and R. R. Dubey, RADIAL DOSE DISTRIBUTIONS IN THE DELTA RAY THEORY OF TRACK STRUCTURE., in Two Center Effects in Ion Atom Collisions, American Institute of Physics, conference proceedings 362 , 1996. (M.E. Rudd symposium Lincoln NE 1964) Editors T. J. Gay and A. F. Starace, pp. 245-265.

C. X. Zhang and R. Katz, THINDOWN IN BIOLOGICAL 1-HIT DETECTORS: E. COLI B/r, AND B_{S1}. Chinese Science Bulletin, 40,1479-1482 (1995).

C. X. Zhang and R. Katz, THINDOWN IN RADIOBIOLOGY: V-79 CHINESE HAMSTER CELLS. Acta Scientiarum Naturalium Universitatis Sunyatseni, China, in Chinese, 34, No. 1, 30-34 (Jan 1995).

C. X. Zhang and R. Katz, Thindown in Radiobiology: E. Coli B/r, Bs-1, B. Subtilus Spores and V-79 Chinese Hamster Cells, Nuclear Science and Techniques (China) 6, 65-70 (1995).

R. Katz and F. A. Cucinotta, Low Dose, Letter to Editor, Health Physics. 68,859 (1995)

F. A. Cucinotta, J. W. Wilson, R. Katz, W. Atwell, G. D. Badhwar, and M. R. Shavers, Track Structure and Radiation Transport Model for Space Radiobiology Studies, Adv. Space Research. Adv. Space Res. 18, (12)183-194 (1996)

F. A. Cucinotta, J. W. Wilson, M. R. Shavers, and R. Katz. ..Effects of Track Structure and Cell Inactivation on the Calculation of Heavy Ion Mutation Rates in Mammalian Cells. Int J. Radiat. Biol. 69, 593-600 (1996).

R. Katz, F. A. Cucinotta, and C.X. Zhang. The Calculation of Radial Dose from Heavy Ions: Predictions of Biological Action Cross Sections. Nucl. Instr. Meth. B. 107, 287-291 (1996)

J. W. Wilson, F. A. Cucinotta, M. Kim, J. L. Shinn, and R. Katz. Impact of Biological Models on Radiation Physics Requirements in Space Radiation Protection. Cospar.

F. A. Cucinotta, R. Katz, and J. W. Wilson, RADIAL DISTRIBUTION OF ELECTRON SPECTRA FROM HIGH ENERGY IONS. Radiation and Environmental Biophysics. Submitted Aug 1997.

R. Katz and F. A. Cucinotta, TRACK STRUCTURE MODELS; APPLICATION TO RADIOBIOLOGY AND HIGH LET THERAPY. Invited Paper. Gianfranco Grossi, Univ of Naples. 1998 to be published.

II. ABSTRACTS AND PROCEEDINGS

F.A. Cucinotta, J.W. Wilson and R. Katz, RADIOSENSITIVITY PARAMETERS FOR LETHAL MUTATIONS IN C. ELEGANS. Symposium on Microdosimetry, Gatlinburg, TN 1992.

R. Katz, D. Ngo, F.A. Cucinotta and J.W. Wilson, CELLULAR TRACK MODEL FOR HEAVY ION BEAM STUDIES, Radiation Research Society, Salt Lake City, March 1992.

R. Katz and M. P. R. Waligorski, ON THE LINEAR EXTRAPOLATION TO LOW DOSES. Radiat. Res. Soc. Dallas, March 1993.

R. Katz. DOSE VS. FLUENCE, Radiat. Res. Society, Nashville, May 1994.

C. X. Zhang and R. Katz, THINDOWN IN RADIOBIOLOGY. Radiat. Res. Soc. Nashville, May 1994.

R. Katz, R. Zachariah, F. A. Cucinotta and C. X. Zhang, RADIOSENSITIVITY PARAMETERS FOR CELL INJURY, Radiat. Res. Society, Nashville, May 1994.

R. Katz, Invited Lecture, Prof. Guy Lemaire, CEA, Bruyeres le Chatel, France, September 1994.

R. Katz and F. A. Cucinotta, Target Molecular Weight, Energy Absorbed VS. Cross Section. Radiation Research Society, San Jose, April 1995

F. A. Cucinotta, J. W. Wilson and R. Katz, Biological Effectiveness of Medium energy Protons Along the Bragg Ionization Curve. Radiation Research Society, San Jose, April 1995.

R. Katz, F. A. Cucinotta and Chunxiang Zhang, The Calculation of Radial Dose from Heavy Ions: Effects on the Prediction of Biological Action Cross Sections. Sixth Annual Space Radiation Health Investigators' Workshop. Brookhaven, May 1995.

R. Katz, Heavy Ion Track Structure in Radiobiology and Dosimetry, Lecture, DOE/EML, New York City.

Same title as 163. Conference on Swift Heavy Ions in Matter, Caen, France, May 1995

R. Katz, Lectures on Track Theory, University of Franche Comte, Besancon, France, May 1995

R. Katz, Lectures on Track Theory, DLR Institute of Aerospace Medicine, Cologne, Germany, 1995

R. Katz and F. A. Cucinotta, Track Theory Update. 10th International Congress of Radiation Research, Wurzburg

R. Katz, Track Theories in Radiobiology, Fifth Workshop on Heavy Charged Particles, G.S.I Report 95-10 Darmstadt August 1995 see extended abstract.

F.A. Cucinotta, J.W. Wilson and R. Katz, Calculations of Action Cross Sections for Inactivation and Mutation, Fifth Workshop on Heavy Charged Particles, ,G.S.I. Report 95-10 Darmstadt August 1995

R. Katz, Radiobiology and Track Structure, Invited Paper, XIV ISIAC, Seattle. 1995

R.Katz, Lectures on Track Theory University of Franch Comte, Besancon, France 1996

J. W. Wilson, F. A. Cucinotta, M. Kim, J. L. Shinn and R. Katz, Impact of Biological Models on Radiation Physics Requirements in Space Radiation Protection, Space Radiation Workshop 1996. also, COSPAR

F. A. Cucinotta, J. W. Wilson, R. Katz, H. Nikjoo and D. T. Goodhead, Radial Dose Model of SSB, DSB, and Deletions and Comparisons to Monte-Carlo Track Structure Calculations, 12th Symposium on Microdosimetry, Oxford U.K. 1996

R. Katz, Gamma-Kill, Ion-Kill; Core-Penumbra Confusion, 12th Symposium on Microdosimetry, Oxford 1996

P. Meyer, J.E. Groetz, R. Katz, M. Fromm, and A. Chambaudet, Simulation of a Microdosimetry Problem: Behavior of a Pseudorandom Series at Low Probability. 12 Symposium on Microdosimetry, Oxford 1996.

R. Katz, F.A. Cucinotta and J. W. Wilson, Calculation of the Microdosimetric Quantity, Mean Specific Energy Squared Z^2_b , as a function of Radial Distance from Heavy Ions. NASA Workshop, Brookhaven April 1997.

R. Katz, Track (Katz) Theory: Predictions and Innovations. Radiation Research Society, Providence May 1997.

R. Katz and F. A. Cucinotta, Estimates of Microbeam Modulated Cellular Effects. Third International Workshop: Microbeam Probes of Radiation Response, Columbia University, New York May 1997.

R. Katz and F.A. Cucinotta, Treatment Planning for High LET Therapy. Radiat. Res. Society. Louisville KY April 1998

R. Katz and F.A. Cucinotta, APPLICATIONS OF TRACK THEORY FOR STUDY OF UNIQUE EFFECTS OF HEAVY IONS IN THERAPY AND CNS DAMAGE. 9th Annual Investigators Workshop in Space Radiation Research, Loma Linda, June 1998

R. Katz and F.A. Cucinotta, IMPLICATIONS OF TRACK STRUCTURE FOR HIGH LET DOSIMETRY. 12 International Conference on Solid State Dosimetry. Burgos, Spain July 5-10, 1998

R. Katz and F.A. Cucinotta, TRACKS TO THERAPY 19th International Conference on Nuclear Tracks in Solids. Besancon, France Aug 31-Sept 4, 1998

R. Katz and F.A. Cucinotta. PREDICTIONS AND CONCEPTUAL INNOVATIONS IN RADIOBIOLOGY, RADIATION PROTECTION AND ONCOLOGY FROM TRACK THEORY. L.H. Gray Conference on Track Physics.

III. CHAPTERS, NASA REPORTS

F.A. Cucinotta, W. Atwell, M.J. Golightly, A.C. Hardy, J.W. Wilson, L.W. Townsend, J.L. Shinn, J.E. Nealy and R. Katz, PREDICTION OF CELL DAMAGE RATES FOR LIFESAT MISSIONS, NASA T.M. #102170 (1990).

F.A. Cucinotta, R. Katz, J.W. Wilson, L.W. Townsend, J.E. Nealy and J. Shinn, CELLULAR TRACK MODEL OF BIOLOGICAL DAMAGE TO MAMMALIAN CELL CULTURES FROM GALACTIC COSMIC RAYS. NASA Technical Paper 3055 (1991)

F.A. Cucinotta, W. Atwell, M. Weyland, A.C. Hardy, J.W. Wilson, L.W. Townsend, J.L. Shinn, and R. Katz. RADIATION RISK PREDICTIONS FOR SPACE STATION FREEDOM ORBITS. NASA Technical Paper 3098, June 1991.

R. Katz and M.L. Varma, RADIAL DISTRIBUTION OF DOSE, in "Physical and Chemical Mechanisms in Molecular Radiation Biology", edited by W.A. Glass and M.N. Varma, Plenum Press, New York (1991).

R. Katz, F.A. Cucinotta, J.W. Wilson and Duc M. Ngo, TRACK STRUCTURE MODEL OF CELL DAMAGE IN SPACE FLIGHT. NASA Technical Paper 3235, October 1992.

F.A. Cucinotta, J.W. Wilson, R. Katz and G.D. Badhwar, KATZ MODEL PREDICTION OF CAENORHABDITIS ELEGANS MUTAGENESIS ON STS-42. NASA Technical Memorandum 4383, November 1992.

J. L. Shinn, R. Katz, F. A. Cucinotta, J. W. Wilson and Duc M. Ngo. CELLULAR TRACK MODEL FOR STUDY OF HEAVY ION BEAMS. NASA Technical Paper 3351, August 1993

F. A. Cucinotta, R. Katz, J. W. Wilson, R.R. Dubey, HEAVY ION TRACK STRUCTURE CALCULATIONS FOR RADIAL DOSE IN ARBITRARY MATERIALS, NASA Technical Paper 3497, February 1995,

F.A.Cucinotta, J.W. Wilson, M. R. Shavers, and R. Katz. CALCULATION OF HEAVY ION INACTIVATION AND MUTATION RATES IN RADIAL DOSE MODEL OF TRACK STRUCTURE, NASA Technical Paper 3630, June 1997



Robert Katz
Principal Investigator
31 October 1998